EFFECT OF EPOXY MATERIALS AND GOLD WIRE NUMBER ON LED ENCAPSULATION PROCESS

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EFFECT OF EPOXY MATERIALS AND GOLD WIRE NUMBER ON LED ENCAPSULATION PROCESS

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LIST OF ABBREVIATIONS

CFD	Computational fluid dynamics
DGEBA	Diglycidyl ether of bisphenol A
DMA	Dynamic Mechanical Analyzer
EMC	Epoxy molding compound
FSI	Fluid-structure interaction
LED	Light-emitting diode
LQFP	Low Quad Flat Packages
VOF	Volume of fluid

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EFFECT OF EPOXY MATERIALS AND GOLD WIRE NUMBER ON LED ENCAPSULATION PROCESS

ABSTRAK

Terdapat beberapa isu mengenai aplikasi LED berkuasa tinggi yang menjejaskan fungsi dan kebolehpercayaan LED. Masalah paling biasa yang berlaku dalam LED semasa proses enkapsulasi ialah ubah bentuk wayar yang boleh menjejaskan jangka hayat LED. Tujuan kajian ini adalah untuk menganalisis pengaruh bahan epoksi yang berbeza dan kesan bilangan wayar emas semasa proses enkapsulasi LED. Dalam kajian ini, ANSYS Fluent digunakan untuk mensimulasikan isipadu bahan epoksi yang disalurkan ke LED dengan menggunakan kaedah isipadu cecair (VOF) dan fungsi yang ditentukan oleh pengguna (UDF). Selain itu, ANSYS Fluent juga digunakan untuk melengkapkan penyiasatan tentang fenomena interaksi struktur bendalir (FSI) antara ikatan wayar emas dan bahan epoksi. Pemodelan FSI digunakan untuk mengukur jumlah tekanan yang dihasilkan secara tidak langsung pada ikatan dawai emas semasa proses enkapsulasi. Simulasi dijalankan dengan mempelbagaikan jenis bahan epoksi (ERL-4221, EMC dan D.E.R.-331) dan bilangan wayar emas (1,2,3,4 dan 5). Ujian eksperimen dijalankan untuk mengesahkan struktur akhir bahan epoksi yang diperoleh daripada simulasi. Keputusan yang diperoleh menunjukkan bahawa ubah bentuk dawai, tekanan dan regangan yang diagihkan pada ikatan wayar meningkat dengan peningkatan ketumpatan bahan epoksi. Selain itu, hasil simulasi pada bilangan wayar emas yang berbeza menunjukkan bahawa semakin tinggi bilangan wayar emas, semakin besar taburan regangan dan tekanan apabila bahan epoksi yang sama digunakan.

EFFECT OF EPOXY MATERIALS AND GOLD WIRE NUMBER ON LED ENCAPSULATION PROCESS

ABSTRACT

There are several issues concerning high-power LED application that affect the functionality and reliability of the LED. The most common problems that occurred in LED during the encapsulation process is wire deformation which can affect the life expectancy of the LED. The aim of this present study is to analyse the influence of different epoxy materials and effect of gold wire numbers during the LED encapsulation process. In this study, ANSYS Fluent is utilized to simulate the volume of the epoxy materials being dispense onto the LED by utilizing the volume of fluid (VOF) strategy and user-defined function (UDF). Besides, ANSYS Fluent is also utilized to complete an investigation on the fluid-structure interaction (FSI) phenomena between the gold wire bonding and the epoxy materials. The FSI modelling was used to measure the amount of stresses indirectly applied to the gold wire bonding during the encapsulation process. The simulation is conducted by varying the types of epoxy materials (ERL-4221, EMC and D.E.R.-331) and number of gold wires (1,2,3,4 and 5). An experimental test was conducted to validate the final structure of the epoxy materials obtained from the simulation setup. The results obtained show that the wire deformation, stress and strain distributed on the wire bonding increased with the increasing density of epoxy materials. Besides, the simulation results on the different gold wire numbers showed that the higher the number of gold wires, the larger the stress and strain distributions when the same epoxy material is used.

CHAPTER 1

INTRODUCTION

1.1 Overview

Light-emitting diode (LED) device with a good quality must have desirable properties such as low power consumption and high efficiency, reliability, and life expectancy. However, it is quite difficult to obtain the LED with the desirable properties as there were several possible factors that could affect the functionality of the device. Alim et al., (2021) conducted a study on the encapsulation process in LED packaging. They listed out several challenges in the LED packaging such as shape of encapsulation, thermal conductivity, packaging material degradation and strength of bonding. Therefore, the failure rates of the LED device can often be attributed to the following factors.

Packaging materials is one of the aspects where a variety of failures could occur. For example, heat from the PN junction of the chip combined with the external surrounding can cause the packaging material of the LED to change in colour and cracked (Xu et al., 2019). Epoxy resins, as top thermosetting polymer materials, have been widely used in the present LED encapsulation process due to advantages such as strong adhesion, exceptional machinability, and great chemical resistance(Shan & Chen, 2018). Hence, three different type of epoxy resins used for the LED encapsulation process will be studied in this paper.

Wire deformation or wire sweep is an example where failures can occur at the wire bonding. When the amount of stress applied on the wire bonding is too large, it will cause the wire to break and cause the LED device to fail (Ramdan et al., 2012). There are several factors that can be the cause of wire sweep formation during the encapsulation process. Therefore, the effect of the gold wire number on LED will be a concern study in this paper. Currently, there are different types of LED encapsulation structures available on the market. The type of encapsulation structure used during the encapsulation process is depending on the type of LED itself (Roslan et al., 2020). For this study, typical LED encapsulation structure will be used which is semi-sphere as shown in Figure 1.1.

In this paper, the influence of three types of epoxy resins and gold wires with varying numbers on the LED encapsulation process will be studied both computationally and experimentally to validate the results acquired. The simulation of the LED encapsulation process will be analyse using a common fluid-structure interaction (FSI) problem, which can be dealt with a coupled analysis of fluid flow and structural deformation using ANSYS Fluent.

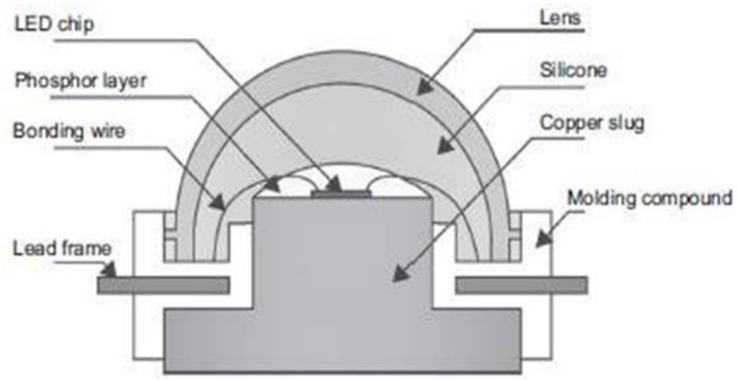

Figure 1.1: Semi-sphere LED Encapsulation Structure (Roslan et al., 2020)

1.2 Project Introduction

LED chip is generally encapsulated by epoxy resin due to its good mechanical strength and metal-adhesion (Lin et al., 2018). In this paper, three different epoxy resins with different properties will be studied to analyse the structure formed during the encapsulation process. One of the materials used in this study will be epoxy molding compound (EMC). EMC are chosen due to its traits of protecting the LED chip from extreme environment such as external physical forces and chemical forces, maintaining the electrical insulation property, and providing a structural support allowing the mounting on the circuit board to be much easier (Komori & Sakamoto, 2009). The other two epoxy resin used are D.E.R-331 and ERL-4221. D.E.R-331 is a Diglycidyl ether of bisphenol A (DGEBA) resin which is the most common epoxy resin while ERL-4221 is a general-purpose cyclo-aliphatic diepoxide that have a good electrical loss properties, good weathering, and high heat-distortion temperature (Huang et al., 2004).

Wire sweep is one of the major defects that can occur in the encapsulation of the LED chip during the encapsulation process. Ali et al., (2014) conducted a study where several parameters of gold wire such as wire length, wire angle, wire pitch, and wire segment were highlighted to investigate the wire sweep performance during the process. However, the number of gold wires in the wire bonding which could influence the wire deformation or sweep is not highlighted in the study. Gold wire is used in this study due to its high corrosion property and good electrical conductivity (Peng et al., 2016). Thus, the influence of five different number of gold wires in LED will be studied and analysed in this paper.

1.3 Problem Statement

Many research studies have been done on semiconductor packaging to improve the performance of the LED. However, there were still many issues that can contribute to the failure of the LED device. For instance, if the type of epoxy material used is unsuitable for the encapsulation process, it would result in the damage or crack in the encapsulant. The crack in the encapsulant can induced more stress to the gold wire which will cause wire deformation. Besides, the difference in the gold wire number for wire bond also could influence wire deformation in the LED. Therefore, this study is conducted to analyse the influence of different epoxy material and the effect of gold wire number on LED during the encapsulation process.

1.4 Objective

The objectives of this study are:

1. To investigate the effect of epoxy resin on LED encapsulant using computational fluid dynamics (CFD)
2. To analyse the effect different number of gold wire on LED encapsulation process using fluid-structure interaction (FSI)
3. To validate the results obtained from the simulation with the experimental result

1.5 Scope of Study

In this study, a modern simulation tool which is ANSYS FLUENT will be utilized because of its computing capability which is used to calculate phenomenon such as flow modelling, turbulence, and heat transfer. This study focused on the simulation of different EMC material dispense into the LED and the interactions between different gold wire number with the EMC during the encapsulation process which is done by Volume of Fluid (VOF) technique and Fluid-Structure Interaction (FSI) method. Moreover, the total amount of stress induced to the gold wire during the encapsulation process also will be analyzed in the simulation. For the results validation, an experiment will be conducted to ensure that the simulation results can be compared with the experimental results. The experiment will be done using the apparatus that have been setup in the lab and the results will be collected by recording using a digital camera.

CHAPTER 2

LITERATURE REVIEW

2.1 Die Attachment, Wire Bonding, and Encapsulation Process in LED

LED are regarded as an ideal replacement for traditional light sources such as fluorescent and neon due to its higher efficiency in numerous applications across scientific disciplines. In the recent years, various improvements and advancement have been conducted that improve the reliability of the LED packaging process (Alim et al., 2021). Alim et al., (2021) had analysed and summarized various developments and innovations to die attachment, wire bonding and encapsulation processes.

Die attachment is one of the significant processes in the LED packaging. In their study, there are four elements that have been investigated which are die structure, die materials, die attachment material, and substrate material. In the die-attachment material section, they discussed on several common material that are used as the die-attachment adhesive such as silicone epoxy resin, silver paste, and eutectic gold-tin alloys. A test was conducted on the silver paste and eutectic to study the effect of the power cycles on the change in the thermal resistance. The graph result of the thermal resistance change of both materials are shown in Figure 2.1. From the results, they found out that eutectic gold-tin alloys have higher thermal fatigue life than silver paste.

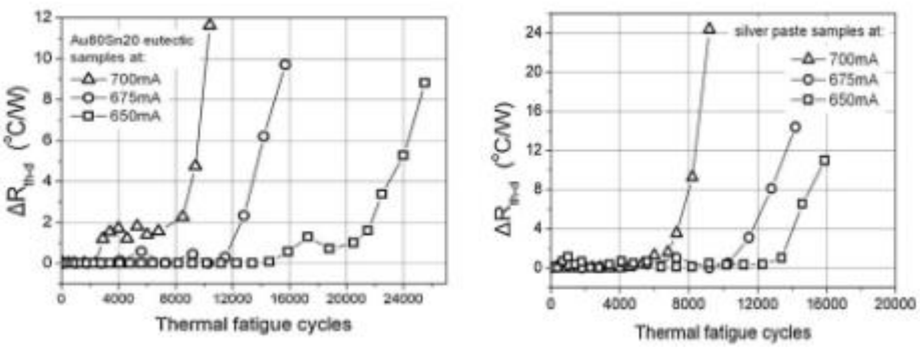

Figure 2.1: Thermal Resistance Curve for Eutectic Gold-tin Alloys and Silver Paste (Alim et al., 2021)

Wire bonding is a structure that is vital in the LED as it is used to transmit power and signal between substrates and chips. In this section, Alim et al., (2021) discussed on the use of several material for wire bonding such as gold, silver, and copper. From their research, they identify silver as an excellent wire bonding option due to drawbacks of gold and copper which are the prices and the resistance in harsh environment respectively.

The limitation on this paper is that the scope of the review is too wide which needs to be summarized compared to the paper with a more focused scope of study. Moreover, the paper focused on the external conditions of the wire bonding compared to this study which focuses on the internal conditions such as stress that can affect the deformation of the wire. However, this paper still has its advantage with its good reference for the wire material as it can contributed to more efficient LED packaging when combined with the results of this present study.

2.2 Properties of Epoxy Molding Compound

EMC are widely used in the electronics industry as a packaging for encapsulating semiconductor materials. During the curing process of this material, residual stress will be induced due to both cure and thermal shrinkage which can lead to product failure (Sadeghinia et al., 2012).Sadeghinia et al., (2012) conducted research to investigate the changes in both elastic modulus and viscoelastic behaviour during the curing process. The experimental shear setup was done by using Dynamic Mechanical Analyzer DMAQ800 instrument to measure the changes in the mechanical properties of the EMC. Figure 2.2 shows the schematic diagram of the toll used in the experiment.

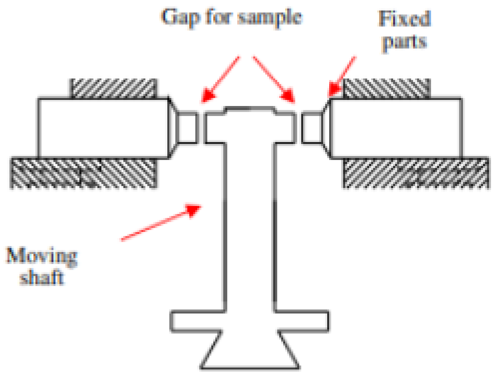

Figure 2.2: Shear Clamps Schematic Diagram (Sadeghinia et al., 2012)

For the viscoelastic behaviour of the EMC, it was determined during an intermittent cure test with the same DMA apparatus. During the test, the shear modulus and viscoelastic shear master curve are extracted to be analysed. Based on the analysis, it is found that by curing the EMC partially, the rubbery shear modulus will increase and the viscoelastic master curve shift to a higher time domain.

The limitation of this paper is that it only focuses on the factor that will affect the properties of the EMC. However, this paper still contributes by emphasizing the properties of the EMC which is useful for the research of the present paper as it uses EMC as one of the materials for the encapsulant.

2.3 Fatigue Life Evaluation of Wire Bonds in LED Packages

LED package reliability is one of the aims of all the improvement and advancement that have been done in recent years. There are several tests that can be done to evaluate the reliability of the LED packages. Thermal shock test is an example that can be done to evaluate the reliability of the wire bonding in LED package. When this test is conducted, the most recognized failure mode is wire neck breakage. However, the thermal shock test for the wire bonding reliability can be very time-consuming (Zhang & Lee, 2014). Zhang & Lee, (2014) proposed to use numerical analysis to evaluate the wire bonding reliability in LED packages in their study. Based on the data point conditions presented in Table 2.2, a few thermal shock experiments were performed.

Table 2.1: LED Package and Test Conditions for Thermal Shock Tests (Zhang & Lee, 2014)

Number of DP	Size	Kind of silicone	Wire diameter (μm)	Wire height (μm)	Wire length (μm)	Wire loop
1	Large	A	25.0	190	1000	L1
2	Large	A	25.0	230	1000	L1
3	Large	A	25.0	190	1000	L2
4	Large	A	25.0	230	1000	L2
5	Small	B	30.0	200	650	L2
6	Small	B	30.0	300	650	L2
7	Small	B	30.0	200	920	L2
8	Small	B	30.0	300	920	L2
9	Medium	A	25.0	280	1100	L3

The plastic strains accumulated during the temperature cycle were computed using finite element models based on these data points. The simulation results reveal that data point 3 has the greatest increase in increment, whereas data point 5 has the smallest increase in increment compared to all the data points. This result shows that the reliability performance of the LED can be affected by wire types, wire height, wire length, wire loop and wire diameter.

The limitation on this paper is that the thermal shock test is very time-consuming. Moreover, although the paper researches on many parameters of the wire for the wire bonding, it does not include the wire number which is the concern of this present study. However, this paper still has its advantage as the results from different parameter of the wires can be used to compare with the results from the present study.

2.4 The Effects of Wire Geometry and Wire Layout on Wire Deformation

Wire sweep is one of the failure modes that can occur at the wire bonding. It usually occurs during the transfer molding process. Wire sweep or wire deformation is a critical issue in the transfer molding process as excessive wire sweep can cause electrical short and device failure due to having contact with the neighbouring wires(Ali et al., 2014). Ali et al., (2014) carried out research to investigate the characteristic of the wire sweep using various wire parameters which are wire locations, mold flow directions, wire lengths, wire pitches and wire angles. This study was conducted on Low Quad Flat Packages (LQFP) using JMP statistical analysis software. Table 2.2 shows the results that have been done on the seven devices.

Table 2.2: Results of Wire Sweep Percentage and Wire Length (Ali et al., 2014)

Device	Wire length (mm)				Wire sweep %			
	X1	X2	X3	X4	X1	X2	X3	X4
Z1	2.66	2.99	2.67	3.52	6.55	5.78	1.86	9.77
Z2	2.79	2.78	2.81	2.85	5.67	6.55	4.14	6.09
Z3	2.78	2.63	2.65	2.65	3.17	3.96	3.76	4.56
Z4	2.20	2.19	2.20	2.19	3.56	3.60	3.12	3.98
Z5	1.68	1.58	1.59	1.58	1.37	0.68	0.66	1.42
Z6	3.31	3.30	3.31	3.30	8.02	6.59	6.70	7.37
Z7	3.25	3.37	3.31	3.25	4.09	3.14	2.21	4.08

Based on the results, it can be indicated that wire length has the most influence on wire sweep percentage compared to the other parameters. It is found out in this study that short wire length is a much suitable choice compared to the longer one for the wire bonding. This is because, when the length of the wire in wire bonding increase, the percentage in wire sweep occurred during the transfer molding process will be higher (Ali et al., 2014).

The limitation of this paper is that the study that had been done did not mention any parameter of wire with different number which is the concern in the present study.

However, this paper is still beneficial for this present study as the characteristic of wire sweep is one of the variables that can be analysed to achieve the objectives in the research paper.

2.5 Comparisons of Epoxy Resins for Applications in LED

LED packaging is designed to act as a protection for LED chip and bonding wires from external forces and pressure that can reduce the life expectancy of the LED. Usually, epoxy resins and silicone resins are two of the encapsulant materials that are used in LED packaging (Kim et al., 2013). Epoxy resins are used due to strong adhesive properties compared to the other encapsulants. Huang et al., (2004) conducted a study on three different epoxy resins to determine the suitable encapsulant for LED applications. The three epoxy resins used in the study are D.E.R.-331 which is a bisphenol A type epoxy resin, Eporite-5630 which is a bisphenol A type epoxy resin modified with a UV stabilizer and ERL-4221 which is a cyclo-aliphatic epoxy resin. A series of reliability tests are performed to compare the properties of the three epoxy resins such as thermal shock, humidity, and lifetime test. The comparison of the three epoxy materials is done by measuring the optical properties of the encapsulated LED and recording the light intensities of the chips using light intensity tester S-370. Table 2.3 shows the results of the reliability test on the three epoxy materials.

Table 2.3: Results of Reliability Test on Epoxy Materials (Huang et al., 2004)

Properties	D.E.R.-331	Eporite-5630	ERL-4221
Initial intensity of LED (mcd)/ standard deviation	2231/324	2276/431	1746/261
Decrease in light intensity after 800 thermal shock cycles (%)	-13.4	-13.1	-17.7
Decrease in light intensity after 1000 h at 85° and 95 RH (%)	-11.5	-8.4	-26.2
Decrease in light intensity after 1000 h use (%)	-8.1	-7.1	-11.2
Decrease in light intensity after 8 weeks solar exposure (%)	-12.8	-9.1	-7.3

Based on the results shown in the Table 2.3, it can be seen that ERL-4221 has higher UV stability compared to the other two epoxy resins. However, the optical properties of the ERL-4221 is lower than the other two due to shrinkage during the curing process. Eporite-5630 and D.E.R.-331 had higher thermal stability than ERL-4221 but Eporite-5630 has a slight advantage due to the addition of UV stabilizer that provided UV resistance. After the comparison of the three epoxy resins, Eporite-5620 is the best choice for the LED application due to balance properties compared to ERL-4221 and D.E.R.-331.

The limitation of this paper is that it only focuses on the changes in light intensity for three different epoxy resins and does not analyse the influence of different properties of epoxy resins on the wire bonding which is the concern in the present study. However, this paper still has its advantages as it provides the properties of the epoxy resins that can be used for the present case study.

2.6 Summary

There are many research papers that study about the LED packaging. Most of these research papers mainly focus on the encapsulant and wire bonding which is crucial in LED packaging process. These research papers have contributed greatly to this present study. Some of the papers contribute by analyzing the properties of different epoxy resins which is one of the main concerns in this paper. Besides, the research studies on the wire bonding are also beneficial as these papers provide several factors that can affect the wire bonding which can increase the accuracy of the results obtained. However, there are still gap in the studies that have been done on the LED packages. The gap is the effect of different epoxy materials on LED encapsulation process. Most research papers only used one epoxy materials for their studies to determine the influence of the material on the LED. Next, the parameter for wire bonding in terms of wire number. The most researched parameters for wire bonding are the wire length and wire diameter thus the reason for this present case study.

CHAPTER 3

METHODOLOGY

3.1 Overview

In the simulation part of the project, a high-power LED model will be created using modelling software. During the simulation setup, some of the parts created in the LED model will be subtracted leaving only the important parts. The boundary conditions for the setup will be discussed in the following section. The simulation results are obtained by repeating the simulation with different epoxy materials and varying the number of gold wires. EMC dispensing experiment is conducted to validate the simulation results with the experimental results. Figure 3.1 shows the methodology flow chart for this case study.

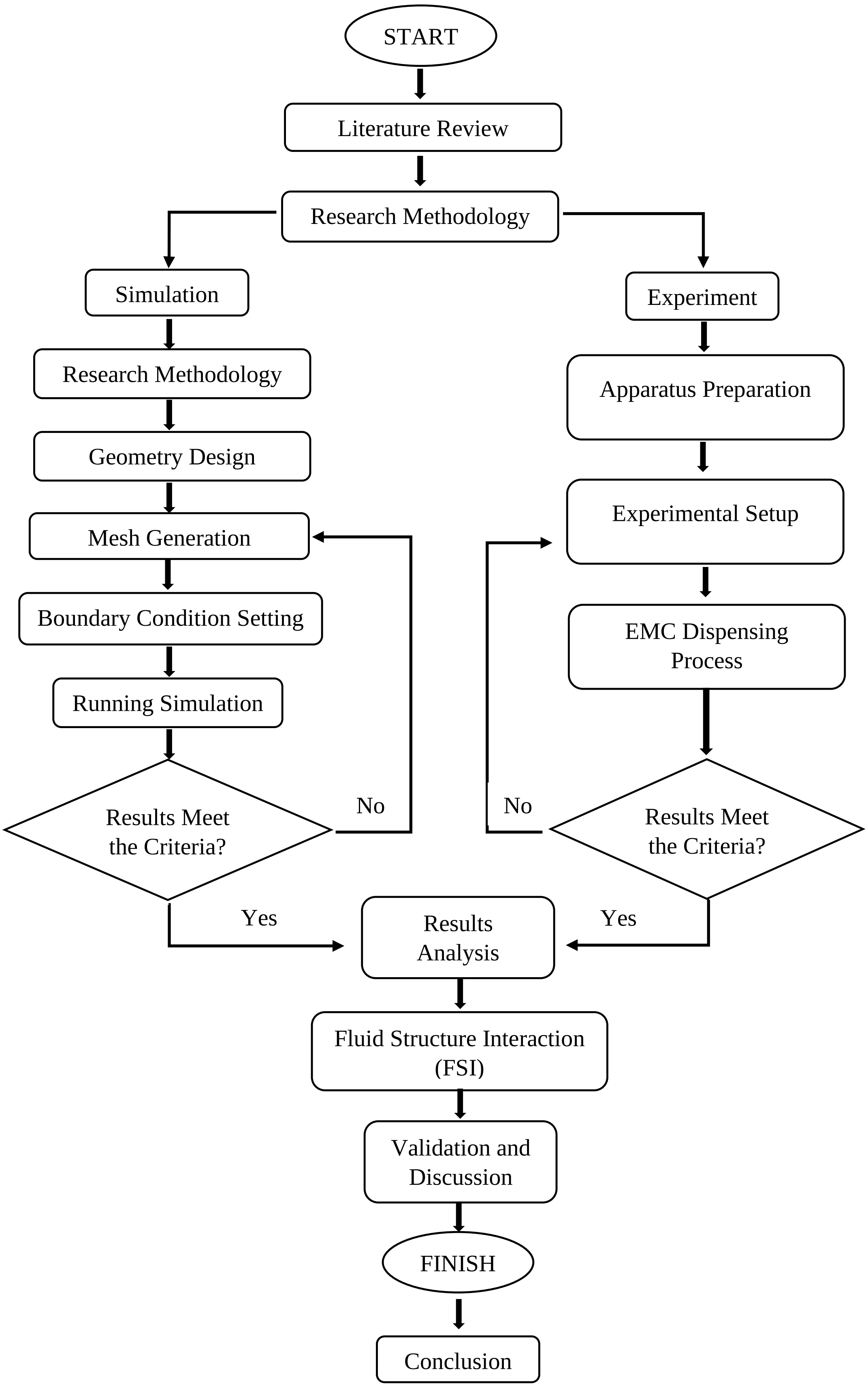

Figure 3.1: Methodology Flow Chart

3.2 Governing Equation

During the virtual modelling, the method used to simulate the encapsulation process of the LED is the Volume of Fluid (VOF) method in simulation software (ANSYS Fluent). The VOF method is utilized to analyse the epoxy resin that is dispensed onto the LED and the interaction between different epoxy resins and gold wire during the process.

The fluid flow movement of the epoxy resins during the simulation can be described by using three-dimensional incompressible flow transport equations which are continuity (conservation of mass), Navier-Stokes, Newtonian fluids, and conversation of energy equations. The equations are written as below:

Continuity (conservation of mass) equation (Khor et al., 2012):

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \tag{1}$$

where u, v and w are velocities of the fluid that flow in x, y, and z axis respectively.

The Navier-Stokes equation for x-direction:

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=-\frac{1}{\rho}\frac{\partial P}{\partial x}+\left[\frac{\partial}{\partial x}\left(\eta\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(\eta\frac{\partial u}{\partial y}\right)+\frac{\partial}{\partial z}\left(\eta\frac{\partial u}{\partial z}\right)\right]+g_x \tag{2}$$

The Navier-Stokes equation for y-direction:

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=-\frac{1}{\rho}\frac{\partial P}{\partial y}+\left[\frac{\partial}{\partial x}\left(\eta\frac{\partial v}{\partial x}\right)+\frac{\partial}{\partial y}\left(\eta\frac{\partial v}{\partial y}\right)+\frac{\partial}{\partial z}\left(\eta\frac{\partial v}{\partial z}\right)\right]+g_y \tag{3}$$

The Navier-Stokes equation for z-direction:

$$\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=-\frac{1}{\rho}\frac{\partial P}{\partial z}+\left[\frac{\partial}{\partial x}\left(\eta\frac{\partial w}{\partial x}\right)+\frac{\partial}{\partial y}\left(\eta\frac{\partial w}{\partial y}\right)+\frac{\partial}{\partial z}\left(\eta\frac{\partial w}{\partial z}\right)\right]+g_z \tag{4}$$

where

ρ = density

u = velocity vector in x-direction

v = velocity vector in y-direction

w = velocity vector in z-direction

P = static pressure

t = time

η = viscosity

g_x, g_y and g_w = gravity in x, y and z-axis

The epoxy viscosity is assumed to be constant at high temperature. So, the Newtonian fluid equation (Khor & Abdullah, 2012):

$$\eta = \frac{\tau}{\gamma} \tag{5}$$

where

τ = shear stress

γ = strain rate

The capacity of the VOF model is to find and elucidate the distribution of the liquid phase by assigning a scalar F in each cell in the computational network. In the model, F indicates the fraction of the cell's volume occupied by the epoxy material. Hence, F takes the value of 1 in the cells containing only the resin, the value 0 in cells void of resin, and the value between 0 and 1 will be in the "interface' cells referred to as the epoxy flow front. Over time, the epoxy flow front will be represented by the following transport equation (Khor et al., 2012):

$$\frac{dF}{dt} = \frac{\partial F}{\partial t} + u\frac{\partial F}{\partial t} + v\frac{\partial F}{\partial t} + w\frac{\partial F}{\partial t} - \left\{\frac{\partial^2 F}{\partial x^2} + \frac{\partial^2 F}{\partial y^2} + \frac{\partial^2 F}{\partial z^2}\right\} = 0 \tag{6}$$

FSI modelling is one of the approaches used to manage the analysis and simulation of the interaction between a fluid (epoxy resin) and a solid body (gold wire). This is due to the stress and strain exerted on gold wire structures in experimental tests are difficult to assess, particularly for LED applications. As a result, this methodology implies an excellent method for observing the interaction between the epoxy resin and the gold wire bonding structures. The stress and strain applied to the gold wire structures when the epoxy fluid came into contact with a solid body might result in deformation and wire sweep during the encapsulant dispensing process. So, in this case, the Navier-Strokes equation, and the solid mechanic equation for the deformation of solid structure are required to simulate the fluid flow as well as the deformation.

3.3 Simulation Modelling

In the modelling of the high-power LED package, the complete geometry is drawn by using SolidWorks software as shown in Figure 3.2. The dimension for the geometry is obtained by measuring the LED prepared for the experimental setup. The completed geometry in the SolidWorks is imported to the ANSYS Workbench so that the simulation can be run. Before the setup for the simulation is run, part like the chip is subtracted by using "Boolean" function in the DesignModeler. The dispensing needle and the domain are defined as the fluid body while the gold wires are defined as solid body

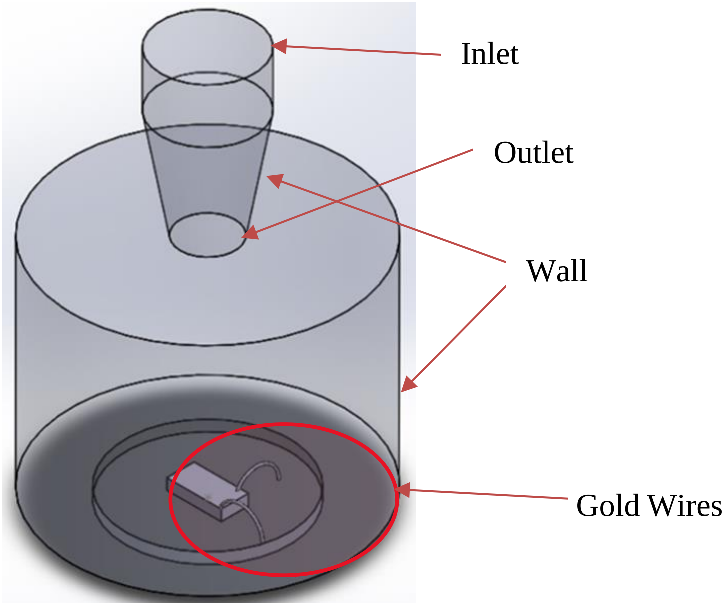

Figure 3.2: LED Geometry in SolidWorks

The 3D domain created needs to be decomposed into a computational mesh so that the calculation of numerical model for each node created can be done as shown in Figure 3.3 and 3.4. The fluid body is meshed with tetrahedral method and linear element order in Fluent due to the complexity of the shape and for reducing the computational time. For the solid body, the method used for the mesh is hexahedral cell with linear element order in the Transient Structural. The statistic of the meshing obtained for the fluid body is 19560 nodes and 98174 elements while for the solid body (gold wire number = 2), the meshing statistics are 36513 nodes and 41760 elements. The quality of all the mesh is set to high smoothing.

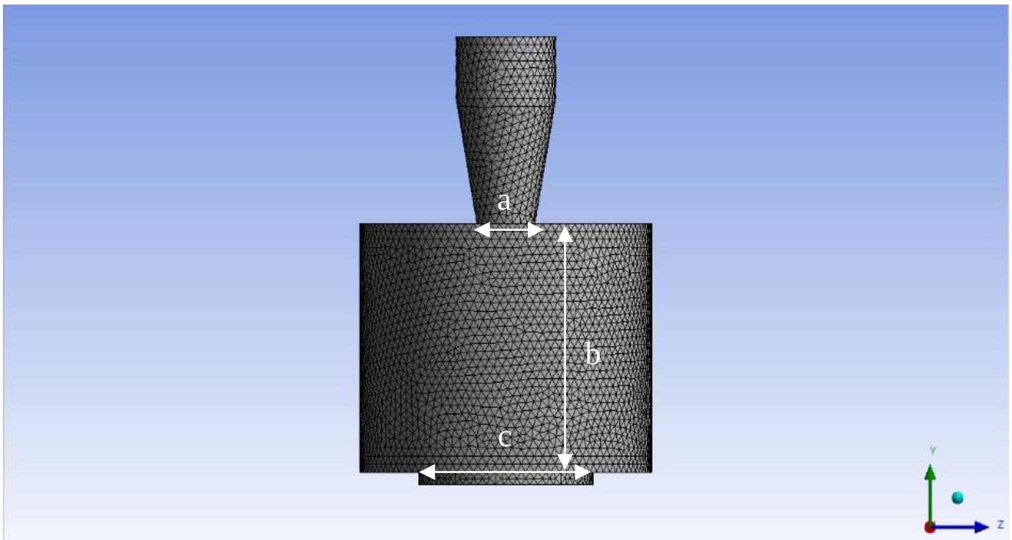

Figure 3.3: Tetrahedral Free Mesh Method with Element Size = 0.15mm.

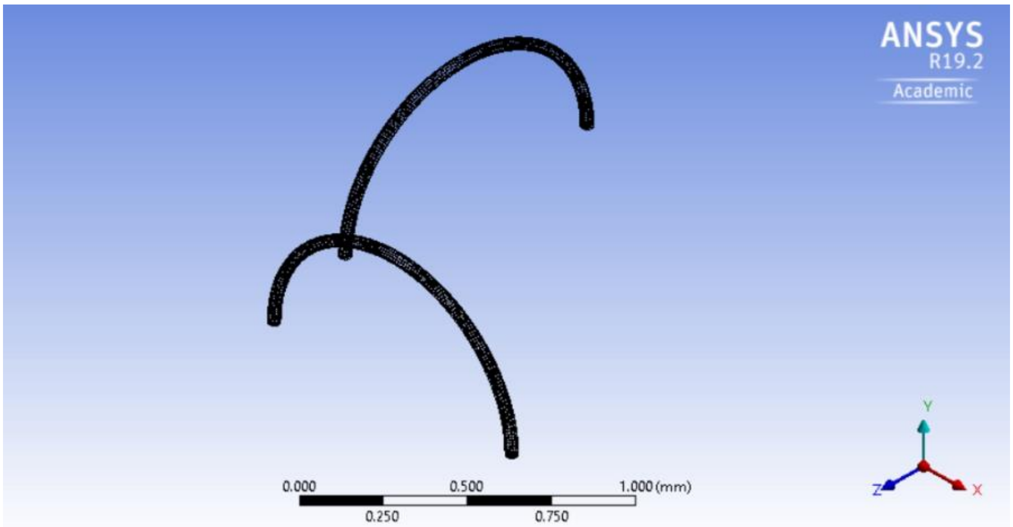

Figure 3.4: Hexahedral Free Mesh Method with Element Size = 0.06mm

In the simulation setup, the effect of the turbulence flow on the encapsulation dispensing process is neglected (Roslan et al., 2020). The Reynolds' number for the ERL-4221, EMC and D.E.R.-331 is 1.57,1.21 and 0.39 respectively. Therefore, the flow is assumed to be laminar. This is due to the absence of obstruction or sharp corner that can create turbulences which makes the process very stable. For each time step of the volume fraction, Volume of Fluid (VOF) scheme and transient-based formulation are applied. In the VOF method, the flow equations are going to be summed up in the volume of a single equation set directly and the interface will be tracked with a phase indicator function. The indicator is used to track the interface between two phases which in this case are air and epoxy resin that has a value of 1 or 0 when a control volume is fully filled. In the setup, air is defined as phase 1 with value 0 while epoxy resin is defined as phase 2 with value 1. Figure 3.5 shows that the red part is the patched region of phase 2 while the blue part is the region of phase 1.

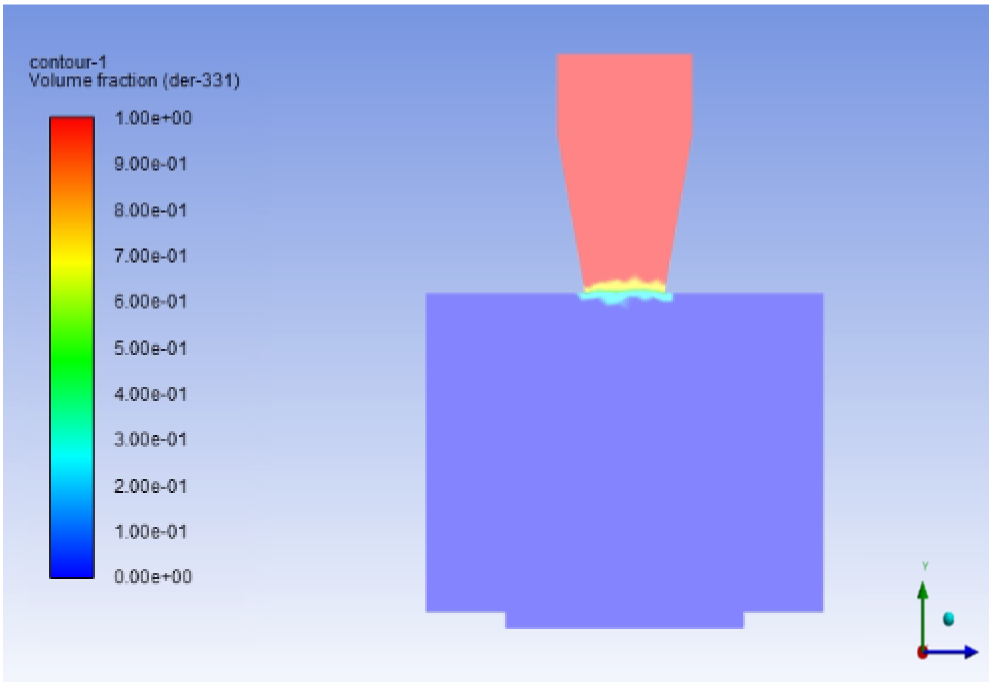

Figure 3.5: Patched Volume Fraction of Epoxy Resin

3.4 Grid Independent Test

In order for computational fluid dynamics (CFD) solver to generate a proper solution, a quality mesh with optimum number of nodes and elements is needed (Chirica et al., 2019). To choose the appropriate mesh element size for the simulation analysis, five models with different element size are examined: Mesh-1 (0.10 mm), Mesh-2 (0.15 mm), Mesh-3 (0.20 mm), Mesh-4 (0.25 mm), and Mesh-5 (0.30 mm). The variable of Von Mises Stress applied on two gold wires by EMC is used to perform the grid independent test for the different mesh size as illustrated in Figure 3.6. Table 3.1 shows the statistic of mesh elements and computational time for each model used in the grid independent test.

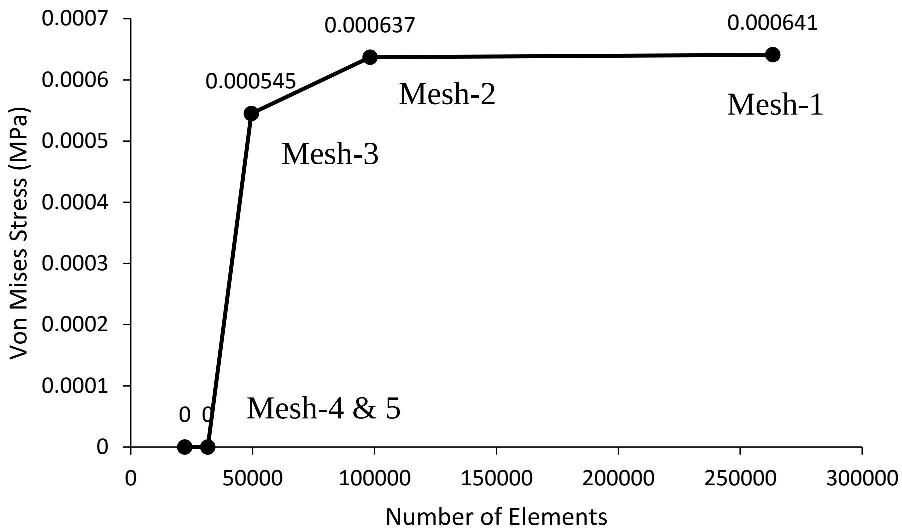

Figure 3.6: Von Mises Stress against Number of Elements

Table 3.1: Statistic of Mesh Elements and Computational Time

Mesh Type	Nodes	Elements	Computational Time (hours)
Mesh-1 (0.10 mm)	50998	263380	10
Mesh-2 (0.15 mm)	**19560**	**98174**	**6**
Mesh-3 (0.20 mm)	10082	49418	3
Mesh-4 (0.25mm)	6503	31613	0
Mesh-5 (0.30 mm)	4605	22171	0

Based on the result in Figure 3.6, the maximum von Mises stress value is used as the variable to make the comparison between each mesh type. The Von Mises Stress value for mesh-4 and mesh-5 are 0 hours due to the inaccurate and low-quality mesh of the geometry. Figure 3.7 shows the mesh error in mesh-4 and 5. The mesh error occurred due to the large element size which is not compatible with the model thus eliminating both mesh-4 and 5 from the selection. For Mesh-1 with 50998 nodes and 263380 elements, the maximum von Mises stress value is 0.000641 MPa. Besides, Mesh-2 with 19560 nodes and 98174 elements, the maximum von Mises stress value is 0.000637 MPa. Henceforth, the percentage difference between both readings is only 0.06% which is less than 1%. Moreover, Mesh-3 with 10082 nodes and 49418 elements, the maximum von Mises stress value is 0.000545 MPa with percentage difference of 14.44%.

For the simulation part, the selection of the mesh type and size are based on the complexity, convergence, accuracy requirements and computational time required to solve the calculation for 1e-5 times step size. From the results of grid independent test, Mesh-2 with 0.15 mm element size is selected as the standard for the simulation in this study. This is because it can generate the similar result with minimal percentage error which is less than 1% compared to Mesh-3 with 14.44% which is a big percentage error. Furthermore, the higher the number of cells, the higher the computation power of the computer is required. The computational time recorded Mesh -2 is 7 hours while for the Mesh-1, the computational time recorded is 10 hours. To conclude, Mesh-2 with the element size of 0.15 mm is chosen as it can save more energy and computing time.

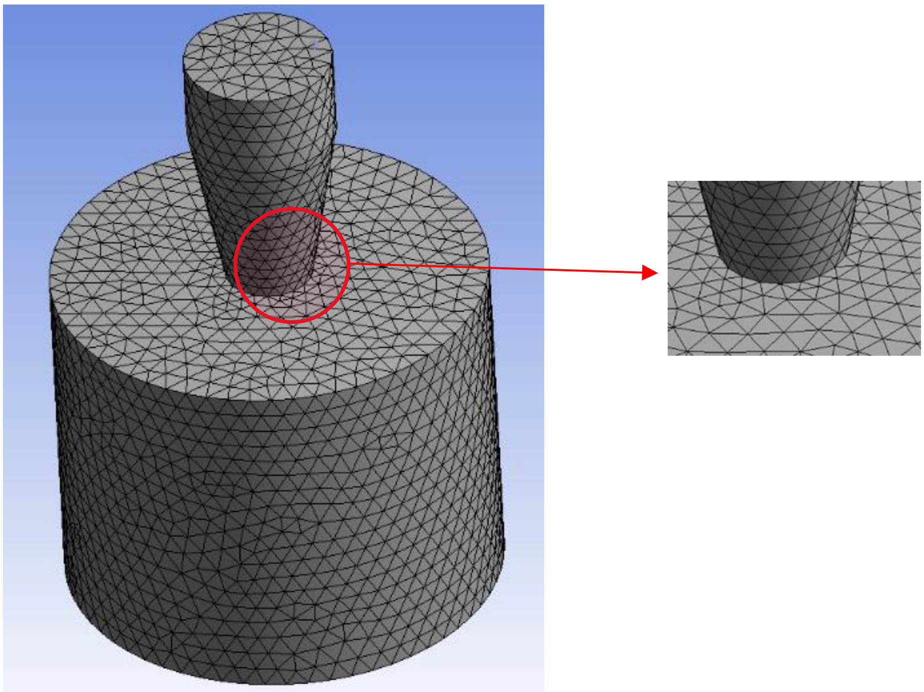

Figure 3.7: Mesh Error in Mesh-4 and Mesh-5

3.5 Material Properties and Boundary Condition

Table 3.2: Material Properties of EMC

Properties	***Epoxy Molding Compound***
Density (kg/m^3)	*1800*
Viscosity (kg/m.s)	*0.448*
Surface Tension (N/m)	*0.005*

Source: (Roslan et al., 2020)

Table 3.3: Material Properties of D.E.R.-331

Properties	***D.E.R.-331***
Density (kg/m^3)	*1159*
Viscosity (kg/m.s)	*0.896*
Surface Tension (N/m)	*0.005*

Source: (Huang et al., 2004)

Table 3.4: Material Properties of ERL-4221

Properties	***ERL-4221***
Density (kg/m^3)	*1173*
Viscosity (kg/m.s)	*0.224*
Surface Tension (N/m)	*0.005*

Source: (Huang et al., 2004)

Table 3.5: Material Properties of Gold Wire

Properties	***Gold Wire***
Density (kg/m^3)	*19300*
Young's Modulus (Pa)	7.85×10^{10}
Poisson's Ratio	*0.42*
Tensile Yield Strength (Pa)	1.84×10^{8}
Tensile Ultimate Strength (Pa)	1.99×10^{8}
Number of Gold Wire	*1,2,3,4,5*

Source: (Swanson, 2018)

Table 3.6: Boundary Condition

Boundary Condition	***Details***
Inlet Speed (m/s)	*0.30*
Injection Time (s)	*0.25*
Inlet Contact Angle (degree)	*175*
Needle Diameter, a (mm)	*1.00*
Distance Needle to Base, b (mm)	*4.00*
Base Diameter, c(mm)	*3.00*

3.6 Experimental Setup

The aim of the LED encapsulation experiment is to validate the results obtained from the simulation with the actual results. For the experiment, the material and apparatus needed are a syringe, a needle with tip of 1mm in diameter, a high-power LED, fluid, and vacuum chamber. Figure 3.8 shows the experimental setup for the experiment. A digital camera is set in front of the needle and LED for the data recording. First, the LED package is placed on a flat surface inside the vacuum chamber to prevent the results from being affected by any external factors. Then, the syringe containing a certain volume of EMC A is injected onto the LED surface. The mold cavity of the LED substrate allows the fluid to form a hemisphere shape. The fluid dispensing process is observed, recorded, and then compared with the results obtained from the simulation.

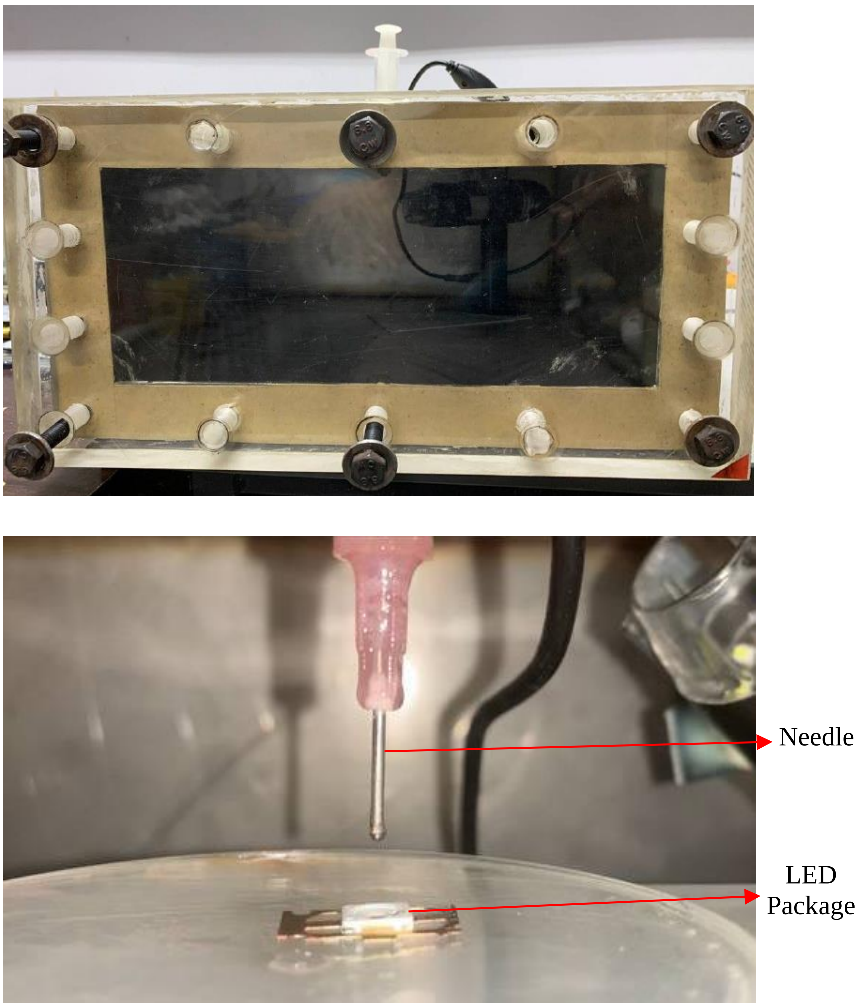

Figure 3.8: Experimental setup for LED Encapsulation Process

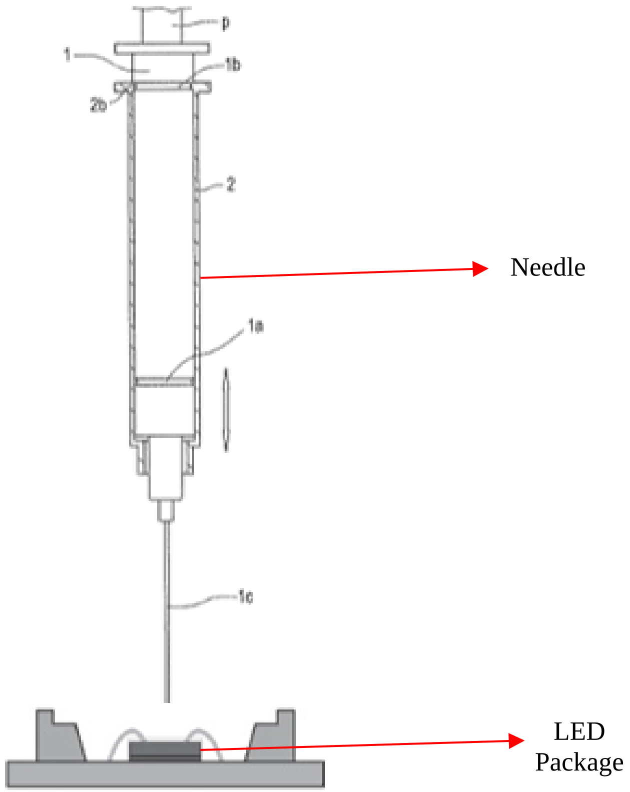

Figure 3.9: Schematic Diagram of Experimental Setup